Report No.

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Aerojet-General CORPORATION

AZUSA, CALIFORNIA

INFORMAL REPORT OF PROGRESS

Copy No.

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TO: Commanding General
Frankford Arsenal
Philadelphia 37, Pennsylvania

Attn: ORDBA, Dr. H. Gisser

SUBJECT: Investigation of Stress-Corrosion Cracking of High-Strength Alloys

CONTRACT: DA-04-495-ORD-3069

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This is the seventh in a series of informal progress reports submitted in partial fulfillment of the contract.

AEROJET-GENERAL CORPORATION

R. F. Kimpel
Assistant Chief Engineer
Structural Materials Division

NOTE: The information contained herein is regarded as preliminary and subject to further checking, verification, and analysis.

I. OBJECTIVES

The objectives of this program are as follows:

A. To study the susceptibility to stress-corrosion cracking of rocket-motor case materials: e.g., Vascojet 1000, Type 300M, and Ladish D6AC steels, AM355 and PH 15-7 Mo stainless steels, and B120VCA titanium

B. To study the environmental parameters, including the atmosphere outside the rocket case, that affect the rate and extent of stress corrosion

C. To determine the effect of material parameters - composition, strength level, welding, micro-structure, surface conditions, etc. - on the stress-corrosion process

D. To devise and evaluate techniques for preventing the stress-corrosion cracking of rocket-motor case materials.

II. WORK PROGRESS

A. INTRODUCTION

The six alloys being evaluated in this program are Vascojet 1000 alloy steel, Titanium B120VCA alloy, AM355 stainless steel, Ladish D6AC alloy steel, 300M alloy steel, and PH 15-7 Mo stainless steel. The environments in which the stress-corrosion studies are being made are those "natural" environments that the alloys are subjected to during the fabrication, testing, and service of rocket-motor cases. Such environments include air, tap water, distilled water, salt water, inhibited water, soluble oils, organic preservatives, chlorinated organic solvents, high humidity, and solid propellant combinations. Owing to the importance of the effect of solid propellants on the stress-corrosion rates of the alloys being studied, the solid propellant environment

will be undertaken at length during the second year of the program, in order that more extensive studies can be made on the most promising alloys. All six alloys at various strength levels will be tested in all of the other environments during the first year of the program, stressed at 75% of the yield strength. To test all the alloys completely by the end of the first year, the environmental stress-corrosion tests will be limited to a period of three weeks in each environment, with the exception of the test in air, which will be conducted for four weeks.

B. VASCOJET 1000 ALLOY STEEL

Testing in 9 of the 11 environments was completed for this alloy. The particular environments in which the testing was completed are air, tap water, distilled water, sodium chloride solution, sodium dichromate solution, marquench salt solution, soluble oil solution, trichloroethylene, and cosmoline. The two remaining environments yet to be tested are the soluble oil and high humidity. The only failures encountered with this alloy were with the specimens stressed at 175,000 to 180,000 psi in the environments of tap water, distilled water, and the sodium chloride solution. See Table 1 for the complete summary of test data accumulated to date. Illustrations of some of the typical failures obtained with this alloy are contained in Report No. 0414-01-3.

C. TITANIUM B120VCA ALLOY

The stress-corrosion testing of this alloy was completed in eight environments, and testing in the ninth environment, air, is nearing completion. The two environments that remain to be tested are the soluble oil and high humidity. Table 2 summarizes all the test data accumulated to date. It will be noted that only four specimens of this alloy failed, two in the sodium chloride solution and two in the trichloroethylene. However, in view of the low stress level and the rapid failure of these specimens, it is believed that these failures were premature and probably caused by cracked or otherwise defective specimens. These specimens are being examined in order to determine the exact cause of failure.

D. AM355 STAINLESS STEEL

The fabrication of two-thirds of the specimens from this alloy was completed, and the environmental stress-corrosion testing of these specimens was initiated in nine environments. Testing has not been started in the soluble oil and high humidity environments. No failures have been noted after two days of testing. The remaining specimens are being cut to proper lengths as the final fabrication step prior to the environmental testing. Table 3 summarizes the mechanical properties of this alloy.

E. LADISH D6AC ALLOY STEEL

The specimen fabrication of this alloy was completed, and the environmental stress-corrosion testing was initiated in nine environments. Testing was not started in the soluble oil and the high humidity environments. No failures were observed after one day of testing.

F. TYPE 300M ALLOY STEEL

The specimen fabrication of this alloy is nearing completion, with the final operation of cutting the specimens to appropriate lengths under way. The exact lengths were determined from the United States Steel Corporation Tables of Tensile Stresses in Bent Beams, the tensile stresses being 75% of the yield strengths reported in Table 4. The environmental stress-corrosion studies of this alloy will begin as soon as the specimens become available.

G. PH 15-7 MO STAINLESS STEEL

This alloy, cold-rolled to approximately 200,000 psi yield strength, was received from the Wallingford Steel Company. Aging cycles were developed to obtain yield strengths greater than 200,000 psi, and the data of this preliminary evaluation are listed in Table 5. Specimens from this alloy were fabricated (transverse to the direction of rolling) and are being aged to yield strength levels to 240,000 psi. After aging and cutting to appropriate lengths, the specimens will be subjected to the environmental stress-corrosion tests.

III. FUTURE WORK

The following testing will be completed by the end of the first year of the program.

A. The stress-corrosion tests of Vascojet 1000 and Ti20VCA Titanium in the soluble oil and high humidity environments

B. The stress-corrosion tests of the Ladish D6AC in all the environments

C. The specimen fabrication and stress-corrosion tests of the AM355, PH 15-7 Mo, and 300M in all the environments

D. U-Bend tests on specimens that show the greatest resistance to the bent-beam testing. This will allow for more severe testing where deemed appropriate.

TABLE 1

BENT BEAM STRESS-CORROSION TEST DATA, VASCOJET 1000*

Yield Strength 0.2% Offset psi x 10^{-3}	Environment**	No. of Specimens	Time to Failure (days)	Total Testing Time (days)
194.0	1	3	NF***	28.0
	2	3		21.1
	3	3		21.1
	4	3		21.1
	5	3		21.0
	6	3		21.1
	7	3		21.0
	8	3		21.0
194.0	9	3	NF	21.0
212.0	1	3	NF	28.0
	2	3		21.1
	3	3		21.1
	4	3		21.1
	5	3		21.
	6	3		21.1
	7	3		21.0
	8	3		21.0
212.0	9	3	NF	21.0
237.5	1	3	NF	28.0

*Stressed at 75% of yield strength

**Environments identified as follows:
1. Air
2. Marquench salt solution, 1 wt%
3. Sodium dichromate solution, 0.25 wt%
4. Trichloroethylene
5. Cosmoline
6. Soluble oil solution, 4 vol%
7. Tap water
8. Distilled water
9. Sodium chloride solution, 3 wt%

***No failure

TABLE 1 (cont.)

Yield Strength 0.2% Offset psi x 10^{-3}	Environment**	No. of Specimens	Time to Failure(days)	Total Testing Time (days)
237.5	2	3	NF	21.1
↑	3	3	↑	21.1
↕	4	3	↕	21.1
↕	5	3	↕	21.0
↕	6	3	NF	21.1
↕	7	1	13.7	--
↕	7	1	14.7	--
↕	7	1	15.7	--
↕	8	1	7.6	--
↕	8	1	7.8	--
↕	8	1	8.9	--
↕	9	1	6.9	--
↓	9	1	10.0	--
237.5	9	1	10.1	--
240.0	1	3	NF	28.0
↑	2	3	↑	21.1
↕	3	3	↕	21.1
↕	4	3	↕	21.1
↕	5	3	↓	21.0
↕	6	3	NF	21.1
↕	7	1	2.7	--
↕	7	1	8.8	--
↕	7	1	9.7	--
↕	8	1	1.8	--
↕	8	1	3.2	--
↕	8	1	4.3	--
↕	9	1	1.2	--
↕	9	1	1.7	--
↓	9	1	6.7	--
240.0				

TABLE 2

BENT-BEAM STRESS-CORROSION TEST DATA, B120VCA TITANIUM*

Yield Strength 0.2% Offset psi x 10^{-3}**	Environment***	No. of Specimens	Time to Failure (days)	Total Testing Time (days)
137.5(L)	1	3	NF****	24.0
↑	2	3	↑	20.8
	3	3		20.8
	4	3		20.9
	5	3		20.2
	6	3		20.3
	7	3		20.9
↓	8	3	↓	20.8
137.5(L)	9	3	NF	20.8
139.6(T)	1	3	NF	24.0
↑	2	3	↑	20.8
	3	3		20.8
	4	2	NF	20.9
↓	4	1	3.4	--
139.6(T)	5	3	NF	20.2

*Stressed at 75% of yield strength

**(L) = Longitudinal
(T) = Transverse

***Environments identified as follows:
1. Air
2. Marquench salt solution, 1 wt%
3. Sodium dichromate solution, 0.25 wt%
4. Trichloroethylene
5. Cosmoline
6. Soluble oil solution, 4 vol%
7. Tap water
8. Distilled water
9. Sodium chloride solution, 3 wt%

****No failure.

TABLE 2 (cont.)

Yield Strength 0.2% Offset psi x 10^{-3}**	Environment***	No. of Specimens	Time to Failure(days)	Total Testing Time(days)
139.6(T)	6	3	NF	20.3
↑	7	3	↑	20.9
	8	3		20.8
	9	1	NF	20.8
↓	9	1	0.00	--
139.6(T)	9	1	0.03	--
149.2(L)	1	3	NF	24.0
↑	2	3	↑	20.8
	3	3		20.8
	4	3		20.9
	5	3		20.2
	6	3		20.3
	7	3		20.9
↓	8	3	↓	20.8
149.2(L)	9	3	NF	20.8
145.6(T)	1	3	NF	24.0
↑	2	3	↑	20.8
	3	3		20.8
	4	2	NF	20.9
	4	1	0.9	--
	5	3	NF	20.2
	6	3	↑	20.3
	7	3		20.9
↓	8	3	↓	20.8
145.6(T)	9	3	NF	20.8
157.8(L)	1	3	NF	24.0
157.8(L)	2	3	NF	20.8

TABLE 2 (cont.)

Yield Strength 0.2% Offset psi x 10^{-3}**	Environment***	No. of Specimens	Time to Failure(days)	Total Testing Time(days)
157.8(L)	3	3	NF	20.8
	4	3		20.9
	5	3		20.2
	6	3		20.3
	7	3		20.9
	8	3		20.8
157.8(L)	9	3	NF	20.8
166.1(T)	1	3	NF	24.0
	2	3		20.8
	3	3		20.8
	4	3		20.9
	5	3		20.2
	6	3		20.3
	7	3		20.8
	8	3		20.8
166.1(T)	9	3	NF	20.8

TABLE 3

MECHANICAL PROPERTIES OF AM355 STAINLESS STEEL*

Evaluator	Testing Direction	Thickness in.	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Rockwell C Hardness
Aerojet	Longitudinal	0.038	245.7	263.0	16.0	53.0
Aerojet	Transverse		199.1	266.5	13.2	53.2
Walling-ford	Longitudinal		250.6	258.9	14.0	**
"	Transverse		210.0	275.5	11.0	52.0
Mellon	Longitudinal	0.038	250.0	261.0	14.5	**
Aerojet	Longitudinal	0.036	249.8	265.8	14.2	54.2
Walling-ford	Longitudinal		259.7	264.4	14.0	**
"	Transverse		226.5	275.5	11.0	52.0
Mellon	Longitudinal	0.036	275.0	265.0	15.3	**
Aerojet	Longitudinal	0.033	278.4	295.1	4.0	55.5
Walling-ford	Longitudinal		298.0	303.0	3.5	**
"	Transverse		251.5	296.0	7.5	54.0
Mellon	Longitudinal	0.033	302.0	311.0	3.8	**

*This alloy cold-rolled to the various strength levels

**Not reported

TABLE 4

MECHANICAL PROPERTIES OF 300M TEST SPECIMENS*

Tempering Conditions	0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Rockwell C Hardness
750°F - 2 hr	195.2	242.1	7.0	47.5
800°F - 2 hr	195.7	239.9	7.5	47.0
	196.4	240.3	7.5	46.5
700°F - 2 hr	208.8	247.0	7.0	49.0
750°F - 2 hr	214.1	255.3	7.0	50.5
	216.5	257.0	7.0	47.5
550°F - 2 hr	232.3	279.6	6.0	51.5
600°F - 2 hr	232.6	278.2	6.5	51.5
	234.3	281.2	6.0	51.5

* Normalized at 1675°F for 1 hour, air-cooled, austenitized at 1650°F for 15 min, oil-quenched, and tempered under the conditions indicated.

TABLE 5

MECHANICAL PROPERTIES OF PH 15-7 MO STAINLESS STEEL

TENSILE SPECIMENS*

Aging Temperature °F	Testing Direction	Yield Strength 0.2% Offset psi x 10^{-3}	Tensile Strength psi x 10^{-3}	Elongation (%) in 2 in.	Rockwell C Hardness
(As received)**	Longitudinal	213.3	218.0	3.5	45.5
(As received)**	Transverse	199.5***	233.3***	3.7***	45.5***
		196.0****	233.0****	4.0****	44.0****
900	Longitudinal	274.7	276.0	2.0	52.0
900	Transverse	264.3	281.8	2.0	52.5
1000	Longitudinal	264.1	267.3	2.0	52.0
1000	Transverse	264.9	279.3	2.0	52.5
1050	Longitudinal	236.7	243.2	2.3	49.0
1050	Transverse	240.9	252.3	3.5	49.5
1075	Longitudinal	215.8	224.1	2.8	48.0
1075	Transverse	225.6	240.9	2.5	48.0
1100	Longitudinal	205.5	214.6	3.8	46.0
1100	Transverse	210.6	226.1	3.5	46.0
1125	Longitudinal	185.4	200.7	5.5	44.5
1125	Transverse	193.1	214.3	3.8	44.0
1150	Longitudinal	165.4	186.9	8.0	43.5
1150	Transverse	185.0	208.5	5.5	43.5

*Aged for 1 hr at the temperatures indicated

**Cold-rolled

***Aerojet data

****Vendor data